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Landslides In India

Dr. Baisakhi Sarkar[1]*

Abstract

Landslides and slope failures are common features affecting the southern face of the Lesser Himalaya. Northeastern ranges including the Naga-Lusai ranges, hills of Mizoram are no exception. Western Ghats also face this problem during southwest monsoon months. It is a chronic problem for a sloping land subject to heavy seasonal rainfall preceded by a hot dry summer.

Landslide may be defined as a form of crustal displacement of rock- mass under the influence of either surface runoff, groundwater seepage or due to earthquake or by some other factors. It causes a rapid dislocation of the mass of rock/debris or residual soil or sediments along or adjoining a slope where the centre of gravity of the moving mass advances in a downward and outward direction. Landslides on a slope formed due to human activities are usually referred to as 'slope failure'.

The magnitude of damage caused by the sudden and unexpected earth movements is huge and it is becoming costlier day by day to tackle the problems associated with these hazards. It is aggravated during and soon after a heavy rainfall. Various corrective and protective measures have been adopted by engineering geologists and civil engineers from time to time. In the process it has been observed that each landslide is unique by itself and, therefore, to control mass wasting and slope failure it is essential to understand the mechanism of slide initiation and its downward propagation together with the causes responsible for these hazards.

The phenomena of landslides and slope failures are studied from two different viewpoints - one that from geomorphological and the other from engineering point of view. Geomorphologists consider landslides as a natural process co-acting in sculpturing the land surface where such phenomena are studied as a significant exogenic denudation process. Whereas an engineer is concerned about the safety of a construction and stability of the base-rock at the site of the structure erected.

Hydrological investigations of landslide areas have attained immense urgency after recent frequent landslides over hills and mountain slopes immediately after a heavy downpour. Rate of surface runoff, percolation and penetration of surface water at landslide spots and along the roads prone to landslides need to be analyzed and effective designs of drainage systems are necessary. Anthropogenic disturbances like bursting of bed rocks by dynamite explosion, movement of heavy vehicles through highways across the hills, deforestation and urban expansion need restriction.

Key Words: *Earthquake, tectonic movement, fragile rocks, cloud burst, glacial lake burst, surface run-off, mud flow, construction work, blasting for tunneling, deforestation, road and building collapse, tunnel hazard.*

INTRODUCTION

Landslides in the Himalayan terrain is a common phenomenon. The Lesser and Middle Himalayan ranges are composed of different types of rocks varying in structural quality and hardness. Relationship between dip slopes of stratum and topographic slopes, drainage density and lithology, structural weak zones and drainage alignments, width of terrace deposits – all are important aspects of consideration to understand landslide proneness of a

[1*]Retired deputy director of National Atlas and Thematic Mapping Organisation, Government of India. Former guest lecturer at Bagbazar Women's College, PG section, Guest faculty member of State University, Barasat and Rashtraguru Surendranath College, Barrackpore, PG section,

terrain.
Himalayan terrain is sculptured by glacial, periglacial and fluvial agencies resulting in varied distribution of surficial deposits. Knowledge of geology and geomorphic processes helps in understanding the intricacies of individual landslides. Climatic factors like melting of snow, cloud burst, heavy rainfall are equally important.
Northeastern hill states are dotted with dissected hill ranges considered as extensions of the Himalayan chain. In Mizoram, the north-south aligned ridges are having surface strata in highly weathered state; these outcrops suffer landslide after heavy rainfall. Construction work of rail-road triggers the problem. The Western Ghats and Deccan Trap country suffer soil creep and landslide due to over saturation of topsoil during southwest monsoon.

Rationale of study: Landslide is a form of crustal displacement caused by the weight of rock mass under the influence of surface runoff, groundwater seepage, earthquake and some other factors. It causes a rapid dislocation of the mass of rock/debris, residual soil or sediments along or adjoining a slope where the centre of gravity of the moving mass advances in a downward and outward direction. Landslides on the slope formed by human activities are usually referred to as slope failures.
Every year landslide and slope failure cause huge loss of resource in terms of loss of property, damage to infrastructure and loss of human lives. To elaborate and mitigate this problem the current discourse is a venture.

Novelty and objective: Quite a few states within India are prone to landslides, like Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland and Mizoram in north India; Maharashtra, Karnataka, Kerala on the west and south, in the lap of the Western Ghats.
Due to expansion of mountain tourism, religious tourism, tourism related to hill resorts, and also due to massive construction work over mountain and hill slopes, frequent land slip is occurring during monsoon and post-monsoon months. This causes serious damage to roads, collapse of buildings and loss of human lives. Each and every year the resource loss involves billions of rupees and immense misery to people affected. Death of human population and livestock is recurring.
Mumbai, the commercial capital of India, suffers serious waterlogging and landslip problem during southwest monsoon; hundreds of people are endangered each and every year. Along the slopes of the Western Ghats, over the Deccan Trap region, landslides cause building collapse, road damage. Tribal population in the villages get buried under rubbles. Construction workers in Arunachal Pradesh do often have the identical fate. So, mitigation of this problem is necessary.

Causes of landslides: The major causes of landslides are linked with unstable slopes and loose surface rocks affected by flowing water. The immediate causes are the followings:
- Increase in load, i.e., weight of the slope forming material.
- Decrease in shearing strength.
- Action of gravity.
- Excess of moisture due to rain or melting snow, alternate dry and wet weather spells.
- Water as transporting agent, increase of pore pressure.
- Addition of load over the upper slope.
- Excavation/undercutting of toe-slope, due to fluvial erosion or man-made action.
- Voluminous slope forming materials (scree).
- Trigger action - immediate effects of earthquake, dam collapse or rock blasting.

As fast and effective transportation is to be extended and properly maintained from the interior of the country up to the international border that passes through the Himalayas, construction work on hills cannot be stopped. As such, effective protective measures and precautionary steps are to taken by the engineering department. Scientists, planners and engineers have to find out possible solution to this hazard. The present discourse is an attempt to throw light on the problem. Due to global warming, cloud burst and copious rainfall is occurring frequently. Heavy surface runoff, breaching of glacial lake-sides are annual events. So, these natural disasters need to be tackled in a cognizable way.

METHODOLOGY

Materials and methods: Materials consulted include publications of Geological Survey of India, reports of Central Road Research Institute, reports of Border Roads Organisation. The author, during her research studies since post-graduation dissertation and extensive work experience related to earth science, resource management and mapping, professional training in remote sensing and its application in understanding Himalayan litho-structure, obtained field- survey based knowledge about many individual landslides.

Publications of Indian Society of Engineering Geology, Indian Society of Remote Sensing, Multimedia/Newspaper reports provided necessary feedback and data. Analysis of individual landslide in terms of geo-tectonic background, geological and geomorphological set up and cognitive deduction of route cause behind the landslide are theoretical knowledge based supported by ground truth. To establish the possible causes behind the landslide occurrences, analysis and discourse on individual landslide with respect to environmental aspects like geology, hydrology, topography, climatic condition, rainfall/precipitation pattern, seasons, soil stability, anthropogenic interferences, impact of global warming and cloud burst have been considered. Suggestions of remedial measures for individual landslides has been given at the last paragraph of each individual case study. No one landslide repeats itself at another spot. Each one is having its own specific character that is to be considered while devising a remedial measure. Remedial action plan would vary from site to site as each and every landslide is unique in terms of lithological composition, steepness of slope, water/moisture present at the site, volume of surface runoff, nature of anthropogenic disturbances, etc.

FACTORS BEHIND LANDSLIDE

Geological factors

Geological factors are related to lithology and structure. Lithology includes type of rock and its compactness whereas the structure includes attitude of bed or stratum or dip of rocks, presence of joints and fractures, folds and faults. These together affect the weathering and erosional potential and formation of debris in a given climatic region experiencing heavy seasonal rainfall.

In the Himalayas, a uniform and continuous lithological set up over a long stretch of land is not common. Within a short distance the rock types and their structural characteristics change. Even within the same stratum the jointing pattern and spacing vary, intensity of folds also changes. Thus, emerges the zones more prone to erosion and degradation. Often the hard rocks encountered are quartzites, gneisses, sandstones; to some extent conglomerate and limestones, whereas the softer rocks are shales, slates, phyllites and schists. The bedding plane in between hard and soft rocks is highly susceptible zone for toe erosion. The abundance of mica in phyllites and schists and clay content in shales and slates make these rocks loose and unconsolidated under prolonged wet condition.

Structure and texture of rocks: The mechanical properties of a rock mass depend primarily on its texture and structure. The mechanical properties of rocks like porosity, permeability, bearing capacity, spatial extension of the stratum, shear strength that directly account for the slides, depend on the inherent properties of the rock texture and its mineral composition. However, the relative spatial arrangement of indiscrete rock masses is more important, it is referred to as ‘structure’.

The structure may be microscopic (small scale), mesoscopic (intermediate scale) and macroscopic (large scale). Some significant microscopic structures are vesicles, micro-voids, etc. Mesoscopic structures that play major role in case of landslides are joints and fractures. Water percolates through these fissures and causes mechanical disintegration, frost heaving, frost wedging. In the road cuttings on steep slopes, the adverse disposition of joint and rock fissures, aided by the lubrication with flowing water leads to saturated

infilling surface/near surface materials, which causes landslides.
The faults and shear zones form well defined weak zones comprising of crushed, pulverized, highly altered and decomposed gauge material. These provide avenues for seepage, resulting in repeated subsidence. Sometimes post orogenic reactivated movement due to intermittent stress release along the pre-existing valleyward dipping fault planes may cause a number of wedges, separated from one another by minor partial slide surfaces, each of these resembling individual fault plane, but of non-tectonic origin. These partial slide surfaces may ultimately join to form a persistent surface along which an abrupt movement could trigger off a block slide.
In the stratified formation of alternating shale and sandstone, there is an inherent tendency of rocks to slide down the bedding plane, where the strata dip in the direction of topographic slope. The situation is worst when the topographic slope is steeper than the bedding plane. When two strata of differential competency come in direct contact, the harder bed slides past the weaker bed and minor drag folds develop in the weaker bed, the plane of separation appears often as abrupt and faulted. The acute angle intersection of the axial plane of the drag fold with the bedding plane point toward the direction of the sliding movement. The drag zone remains highly unstable due to repeated stress release.

Dip direction and topographic slope: The dip direction of rock stratum as well as topographic slope is important. In the sedimentary rocks of the Siwalik foot hills and the metasedimentary rocks of Lesser Himalayas, less steep surface slopes often follow dip of rocks, the topo-slope segments being gentler than the dips (due to aggradation). In case of middle Himalayan region, the topographic slopes are erosional and do not bear a marked similarity with the dip of strata.
Various types of landslides like rotational slide, block gliding, subsidence, creep, rock slide, etc. have been identified, depending on the morphological features of the slide wedges. Though the immediate driving force to destroy a slope is gravitational pull and the most common natural agent to reduce the shearing strength within the earth-mass is excess moisture, the geological structure and lithological composition plays the most important role as route cause of landslides.

Geomorphic factors

Geomorphic factors refer to the details of surface geometry of the terrain and its genetic aspects. There are both erosional and depositional forms, involving the study of slope, gradient and drainage. In Himalayan ranges the diverse litho-structural set-up is being affected by glacial, periglacial and fluvial agents of denudation. The rugged slopes are being continuously denuded and washed out by fluvial agents and debris are transported as suspended load or bed load. In this process, huge debris and sediments are accumulated at break of slope region further downstream.
The drainage pattern and drainage velocity are controlled by litho-structural-slope factors. Smaller first and second order channels follow surface slopes, but higher order channels follow major joint patterns and fault traces in rocks. In valley development, valley-side slopes are generally very steep and the consequent streams draining them have funnel-shaded large catchments in the headward portion. These streams bring huge debris and deposit the load as alluvial fan at the confluence. This causes shifting of the thalweg (line joining the deepest points along a river bed) of the main river. A good number of unpaired terraces are formed along the valley-sides. During earthquake these terraces could get dismantled and might cause blockage of drainage flow and landslides.
Action of water in many forms have caused landslides, toe erosion and damage to structure. Heavy rainfall, snowfall and accumulation of scree material in talus-form, result in boulder and coarse material deposition over roadsides. Accumulation of moisture/ water/ snow in cleavages of fissured rock result in rock disintegration and related damage to roads and other structures. Absorption of water in the soil during heavy rainfall results in road collapse, subsidence of bridge.
Toe erosion in Teesta is the reason behind Rang-Rang slide. Heavy floods cause building collapses, soil erosion and damage to roads. South and East Sikkim as well as Darjeeling

and Kalimpong districts of West Bengal are well known for landslides. The slope failure damages vegetation cover and causes the loss of top soil. It exposes the bedrock for further denudation.

Types of slides: On the basis of the type of movement of debris the affected area may be designated as any one of the followings, viz., Falls, Slides, Flows or Complex slides.

- In **Falls** rock fragments travel freely as individual fragments without any integration with one another.
- **Slides** occur due to shear failure along the contact planes of the overlying surface. The common type of slide is rotational slump of cohesive material. These slides are evident from the development of tension cracks at the root of the slide and bulging of the bottom generally referred as 'tongue'. Rotational slumps are common in alluvial terrace formations which have consolidated over the years and which have fractions of clay.
- **Flows** are landslides in material with very little shear resistance. In areas where the soil mantle consists of silty material in an unconsolidated state mixed with weathered fragments of rocks, flows normally take place. This phenomenon is frequent when the materials involved are saturated with water.
- **Complex slides** possess a mixture of characteristics prevalent in Falls, Slides and Flows.

Climatological factors

Climatological factors include heavy rainfall in a particular season preceded by a hot summer. High temperature promotes melting of ice and snow. Beating by large raindrops also leads to melting of top layer of ice. If the terrain is a sloping surface, cloud burst will cause heavy and rapid surface runoff.

Hot summer with low relative humidity causes weathering of exposed stratum especially where there is scanty vegetation. During rainfall water penetrates subsurface and makes the topsoil loose and prone to sheet wash. In periglacial regions frost action in terms of frost heaving and wedging makes the crust loose and fragile.

Anthropogenic factors

Human interference in terms of clearing of forests/indiscriminate cutting off trees for agriculture, terrace cultivation; construction of multi-storied buildings, road, railway and river bridge, tunnel construction and blasting of rocks using explosives, construction of reservoirs, hydro-power projects, construction of heavy structures, over population and anthropological nuisances; heavy vehicular traffic – all contribute for slope failure**.**

CASE STUDIES

A good number of landslide spots from all over the Himalayas and the Western Ghats have been cited below for site specific discussion; the case sequences are narrated below:

Khooni Nala bridge and tunnel site on NH 44, Ramban, Jammu.

The Khooni Nala bridge and tunnel site (built in1970) is located about 175 km from Jammu on Jammu -Srinagar national highway. The bed rock at the site consists of highly jointed gneiss with phyllite and schists bands. The twin problems of the site are shooting boulders rolling down the steep valley side slopes overlooking the bridge site and unstable bedrock underlying the foundation of the bridge.

The nala (stream) flows on a bed slope of $45° - 50°$ with the horizontal plane in a north-northwesterly direction. The boulders which roll down the steep valley sides are derived from weathered and jointed rocks constituting the left bank of the nala; having open joints, step like topographic relief controlled by joint patterns, scanty vegetation. The vegetation covered right bank is relatively stable.

The profusion of adversely oriented joints all along the nala face extending from below the road level to about 800 m above the subway, the steep profile of the nala and weathered valley side, scantily vegetated hill slope has posed the problem of shooting boulders from above.

In order to protect the Khuni nala bridge from the impact of boulders rolling down the steep nala bed as bed load and shooting over the subway, as well as to control the existing slide zones, rock bolting of the critical zones along the left abutment has been recommended by engineering geologists.

Landslides in Himachal Pradesh

Himachal Pradesh displays a rugged terrain with elevation range from 320m to 6975m; elevation increase from southwest to northeast. The litho-components are having an origin from Indian craton; their age ranges from Paleoproterozoic to Recent. As Indian craton collided with Asian plate some 50-60 million years ago, rock sequences were intensely folded and thrusted due to immense pressure created during movements.

The sub-Himalayan sequence, known as Siwalik group, is dominated by Paleocene to Pliocene sedimentary layers. Sedimentation started prior to plate collision and continued up to late Miocene. Deposition environment changed to shallow marine to continental. A period of non-deposition occurred during Oligocene due to temporary upliftment of Indian continent and regression of sea. The sub-Himalayan sequence thrusts southwestward along the Main Boundary Thrust during Quaternary. Within the sequence rocks have been thrusted and accreted vastly, forming a sub-Himalayan Thrust Zone in southwest Himachal Pradesh It is bounded by Krol Thrust and Tons Thrust.

The Lesser Himalayan sequence dominantly consists of metasedimentary rocks, meta-volcanic rocks and gneiss strata; green schists and amphibolite facies are also found. The sequences are bounded by the Main Central Thrust on the top.

Due to very dry weather in summer, followed by extremely heavy rainfall during monsoon and rugged topography with scanty vegetation Himachal Pradesh has become landslide prone. In the present decade flood and landslide in Himachal Pradesh has been the breaking news of every year. According to reports of Indian Space Research Organisation, all the twelve districts of Himachal Pradesh are prone to landslides.

On 14th August 2023 due to extremely heavy rainfall on 12th/13th August following a cloud burst, flash flood and landslides created a havoc. It affected the entire state. At least 22 people died; 43 roads were blocked and damaged. Numerous buildings, cars, roads, livestock and human population were washed away. Rescue operation was challenging as rocks/debris continued to fall. In Kinnaur, at least 13 people died and dozens were trapped; maximum damage was reported from Mandi, Kangra and Chamba districts. In Shimla two persons were killed as boulders hit their cars. The cause of landslide was flash flood over loose parent rocks.

Landslides in Patalganga-Belakuchi area, Uttarakhand.

In Uttarakhand, Belakuchi area on Alaknanda river bank near the confluence with Patalganga often experiences severe landslide disaster. A cloudburst resulted in flood in Patalganga river and activates mass-wasting and removal of huge boulders in the catchment. The narrow constriction of Patalganga channel was chocked and a lake is formed on its way. The bursting of the lake resulted in flood pulse in the Alaknanda river. Due to toe erosion a series of landslides developed in immediate vicinity of the river channel. Parallel to these were the subsidiary landslide scars in the mid-slope zone of the valley.

Thus, the main cause appears to be linear degradation; materials from either side of the valley were dropped and were carried away by the river as bedload. A large fan at the confluence point of Patalganga with Alaknanda confined Alaknanda waters to the right bank where toe erosion occurs.

Water is the principal enemy of stable slopes. The increasing moisture and pore pressure on the slope surface constituted of unconsolidated material and formation of slip planes in the subsurface along piezometric level, activates mass movement. During floods although the floodwater of the main river seldom reaches the upper level of the valley-side slope yet landslides/ debris creep occurs due to seepage from subsurface aquifer that makes the thin layer of top soil highly unstable.

Along the roads that pass along the concave side of the river bank composed of unconsolidated material, toe erosion occurs. The road foundation develops cracks, and it ultimately collapses.

Landslide in Silkyara Tunnel of Uttar Kashi, Uttarakhand.

Silkyara Bend-Barcot Tunnel in Uttarkashi is a part of Chardham Mahasangh Parijojna (plan to connect four prime pilgrimages). Silkyara-Dandalgaon tunnel project aims at construction of 4.531 km long two-lane bi-directional tunnel (along with 328m approach road) with escape passage on Dharasu-Yomunotri in the state of Uttarakhand.

A portion of the tunnel under construction collapsed on 12th November 2023 at approximately 5.30 A.M. Whilst under construction, a section of the tunnel collapsed, trapping 41 construction workers inside. The 60 m long blockage occurred about 200 m from the entrance of the tunnel. By the skillful planning of experts and earnest hard work of rescue workers all the entrapped personnel were rescued on November 29th, 2023 after a 17-day long untiring effort.

Silkyara, as the name indicates, the prevalence of phyllite in the rock composition; in addition, there are highly fragile meta-shales. These metamorphic rocks are soft and weathered; the debris collapsed inside the tunnel covering 60 km of tunnel length included boulders, gravels, pebbles, sand and dust in enormous volume.

This tunnel is located in proximity to the Main Central Thrust of the Himalayas which is a major geological fault and a shear zone. The Border Roads Organisation opined that collapsed portion of the tunnel had its alignment through an extremely weak rock-mass constituting of meta-siltstone and phyllites. Hence, the terrain over which this tunnel construction is going on is potentially unstable in terms of litho-components as well as tectonic status.

The terrain comprises of meta-volcanic and sedimentary sequences of Garhwal Group represented by quartz, mica schist, chlorite schist, meta-shales, granite gneisses with inter bands of mica schists, carbonaceous phyllites, dolomitic marble and quartzite. The rocks of the tunnel area are mostly phyllite, shale, limestone, underlain by quartzite. The problem related to its lithological composition is due to varied types of rocks with variation in hardness and strength. Some are soft, loose and unconsolidated. This makes the site inherently unstable.

The Himalayas are one of the world’s youngest mountain ranges, formed about 45 million years ago as a result of the collision of two continental plates (Angara-land and Gondwana-land) and folding of sediment layers spread across the Tethys Geosyncline. The upward rising of this mountain chain is due to frequent seismic activities; it is an earthquake prone zone. Garhwal Himalaya, the source area of the Ganga and its major tributaries, sustains over 600 million population. The landscape is dotted with glaciers, forests, waterfalls and springs.

Regional climate is influenced by the terrain as it serves as one of the important carbon sinks. It is here that Char Dham highway project has been planned. It involves widening of existing highways to double-lane paved shoulder ones with about 16 bypasses, realignments and tunnels, 15 flyovers and more than 100 small/ medium bridges. There are two main road tunnels planned for this project; the Silkyara tunnel and a shorter 400 metre tunnel in Chamba.

Apart from these construction plans, there are tunnels being bored for railways and hydel-power, including those to be constructed for overall railway link. There are 33 state-run hydro-projects in operation, and another 14 are being planned.

There has been an intensification of construction work during the last 20 years. But these mountain strata are not everywhere strong enough to tolerate the boring, drilling and loading activities.

Disaster in Kedarnath temple area, Uttarakhand.

On 16th June 2013, a cloudburst in the northern state of Uttarakhand caused devastating flood and landslides that destroyed several villages and towns. Following a cloudburst downpour, there occurred rapid melting of ice and snow on the Kedarnath mountain, about 6 km upward from the Holy Shrine. On 17th June thousands of people were swept away by sheet flood due to combined effect of melting of Chorabari Glacier and breaching of

Chorabari glacial lake. It was a glacial lake outburst flood after heavy rainfall from early monsoon clouds. A massive flood downstream killed more than five thousand people and caused heavy damage to Kedarnath area and downstream, the shrine however, was miraculously saved by a huge boulder transported as bedload and deposited just behind this centuries' old temple.

Though some parts of Himachal Pradesh, Haryana, Delhi and Uttar Pradesh in India experienced heavy rainfall; some areas of western Nepal (Sudur Pashchim Pradesh and Karnali Pradesh), some parts of Tibet also experienced heavy rainfall there were less damages and casualties. Over 89 percent casualties occurred in Uttarakhand; death toll was 6,054 persons; the total included 934 local residents affected fatally by valley-side flood; rests are tourists.

Destruction of bridges and roads left about 300,000 pilgrims and tourists stranded in the valley. Indian Air Force and para-military troops evacuated more than 110,000 people from the flood ravaged area.

According to official source, more than 1,000 landslides have occurred in Uttarakhand, killing more than 48 people so far in the year 2023. Much of the massacre has been attributed to excessive monsoon rainfall.

Road and building damage in Joshimath

This year (2023) in late summer, cracks developed in hundreds of buildings belonging to residents of Joshimath, a small pilgrim centre. A good number of roads also fractured, subsided and collapsed due to endogenic processes operating beneath. Environmental research indicates that the top soil in this area is being depleted three times quicker than the national average rate. Terrain specific approach in all tunnel construction projects, emphasizing the susceptibility of local lithological components to tremor, instability and prone to disintegrate - are to be taken under consideration. Infrastructure development in the Himalayas should prioritize being disaster and climate resilient.

Landslide in Pithoragarh district, Uttarakhand.

On 18th August 1998 at 3.00AM, a massive landslide wiped away the entire village of Malpa in Pithoragarh district of Uttarakhand (the then a part of Uttar Pradesh). The affected area was located in the Kali valley of Higher Kumaon Division of the Himalayas. The rock fall started on the 16th of August 1998, bringing down huge fragments of rocks that initially killed three mules. The ultimate death toll was 221 human population including 60 pilgrims traveling to Tibet as part of Manas-Sarovar and Kailash pilgrimage. Huge chunks of slate tumbled down the roadside slopes.

While rainfall is the triggering factor the other aggravating factors causing landslide were deforestation, blasting of hillslopes for construction work, haphazard cutting of hill slopes and inducing change in natural drainage course. The earthquakes of 1979 and 1980 and subsequent tremors might have been related to this landslide; it was attributed by a report from Wadia Institute of Himalayan Geology.

Landslide and erosion problem in the Kosi catchment area

Catchment area of River Kosi is about 35,000 sq km, drained by three main tributaries, namely Sun, Arun and Tamur. Although in terms of catchment area Tamur contributes 10 per cent, it brings about 26.3 per cent of the coarse silt. Deposition of coarse bedload in Kosi canals is posing a serious problem. Soil erosion and landslide aggravate the trouble. The rainfall from southwest monsoon progressively increases from about 165 cm in the foothills (Terai) to about 320 cm in the southern slopes of the Himalayas, close to Tibetan plateau. Further north, in the rain shadow area of southern Tibet it is only 30 cm.

The hilly catchment is composed of granite, gneisses, schists, crystalline limestone, shale, silt-loam with calcareous nodules; Younger geological formations are often unconsolidated. The outer Himalayas in Nepal have identical structural characteristics as the Siwaliks in the Western Himalaya.

The Kosi is notorious for its vagaries and desolation due to its seasonal flood and frequently shifting course over the north Bihar plain. Within the past 180 years, the river has shifted from east to west over a distance of about 120 km; the direction of shifting might get reversed after a mighty seismic tremor. Entire Kosi watershed is a highly active seismic zone as evidenced from past earthquakes of high magnitudes (years: 1833, 1903, 1934, 1987, 1989, 2015). Occurrence of landslides is a common phenomenon in the upper catchment area located at the subduction zone of the Indian plate with the Tibetan plate.

During its continuous shift, Kosi river has deposited sand over extensive agricultural tracts of Bihar (Purnea and Saharsa districts) in India and southern Nepal. Between 100 metres and 3,500 metres of elevation the land is intensively cultivated and population density is fairly high; forests have been cleared off in favour of cultivation. This has resulted in widespread soil erosion.

Geo-textile work on slopes and reforestation is necessary in the upper catchment to prevent top soil erosion and also for reduction of sediment load in the middle and lower reaches. Pasture furrows are valuable in conserving water and reducing the scour of soil. Wide and low, grassed waterways prove effective in harmlessly disposing off surface run-off. Small dams capable of temporary storing flood water and regulating their discharge through a pipe seem effective. Gully-control works, such as debris dams and drops, prove effective, at least locally.

Landslides in the Teesta river valley in the Eastern Himalaya

Sudden floods in the Teesta river of the eastern Himalaya result in severe catastrophes. The causes of flood in the main river are cloud-burst in the tributary catchment, river aggradation, formation of temporary reservoir due to bottlenecking, choking of the channel by landslide material, excessive bedload and bursting of lakes. The effects are damages to roads including national highway, bridges and other structures, demolition of houses, formation of thick terraces, widening of river courses and minor changes in thalweg (river line).

The foothills of the Lesser Himalayan zone receive a high amount of rainfall (exceeding 400cm) in the rainy season (June- October). This is followed by a dry spell when the northwest part of the Teesta basin receives discharge from melting snow till the advent of winter. Valley -side slopes are in general are ranging from 30° and above. The first order streams incised over the hill slopes are having nearly straight channels. Thus, the terrain reveals a rugged topography.

The entire precipitation received by the territory of Sikkim runs off towards the central north-south axis, i.e., the course of the Teesta river. All other water courses like Lhonek chu, Lachen chu, Lachung chu, Rongni chu, Rangpo chu contribute into Teesta flow. River Rangit also joins Teesta at a point south of Melli Bazar located on the western slope of Kalimpong hill.

In the north, up to Mangan, the Teesta flows through hard gneisses. The valley is steep and narrow. Downstream the river cuts through Dalings consisting of low grade phyllites, hornblende, schists and quartzite; the valley gains width. Most of the tributaries join the main river by descending down steep hill sides. The heavy silt load transported by these streams produces alluvial cones. Along the main river, terraces exist at high as well as low level. These are made up of quartzite, phyllite, schists boulders set up within sand and silt compounds. Sikkim falls under highly active seismic zone. Hence any structure to be constructed should be capable of resisting both horizontal and vertical shocks.

Common types of landslides:

- Rock fall and debris fall due to gravitational force on upper slopes, especially on scarp slopes.
- Debris slide dip – slopes of phyllites and schists- upper and middle slopes – downward sliding of roads with foundations.
- Debris slide and creep – formation of slip planes.
- Stream and river induced slides – erosion, transportation aided by gravitational force – undercutting and toe erosion, slope-debris slide and plant uprooting, silting and choking of rivers.

Flood from South Lhonak Lake in North Teesta Basin

On the night of 3rd October 2023, a glacial lake outburst flood from South Lhonak Lake in North Sikkim caused massive devastation. Located approximately 60 km downstream from the breaching spot, in Chungthang town, the1,200 MW Teesta III dam functioning since 2017 was destroyed; forty lives were lost, seventy six persons were missing and extensive damage to infrastructure happened. Thirty-three bridges, sixteen roads including National Highway 10 were damaged.

Reservoir of Chungthang dam was full to the brim due to incessant rainfall, holding approximately 5 million cubic metres (mcm) of water. Within 10 minutes, the dam collapsed, wreaking havoc to Chungthang town; the Indian Army's forward base stationed there suffered serious damages. It may be noted that Chungthang is a small town at the confluence of the Lachen chu and Lachung chu; the combined flow downstream, is known as the Teesta river.

On 4th October 2023, further downstream, the floodwater damaged the 510MW Teesta-V power station and adjacent bridge. Bolstered by the reservoir water, the water rushed down the hills, scouring the hill-side slopes, triggering landslides. Such was the velocity of flow that it took only one hour and forty minutes for the floodwater to reach Singtam (a distance of 92 km and a drop in gradient of 378 m); 36 minutes from Singtam to Kirney, near Melli, West Bengal (a distance of 25.4 km and a drop in gradient of 120m); and 30 minutes from Melli to Teesta Bazar, West Bengal (a distance of 4.2 km and a drop in gradient of 10m).

The glacial lake burst flood in Sikkim might have been an ecological event; however, the disaster and destruction aftermath were definitely compounded by the cascade dams constructed along the path of the Teesta. The floodwater carried away everything on its path - people, livestock, buildings, bridges, vehicles, construction equipment. Parts of National Highway 10, which had already been ravaged by landslides due to monsoon outburst, drilling activity and tunneling work for railway, were damaged.

The area is geologically unstable as being composed of schists, phyllites and quartzites. The intensive metamorphism is attributed to interlaminated injection of granites. The bedding planes have steep dip making the stratum slide-prone. Soil mantle contains weathered fragments of rock debris. They have as parent material micaceous schists and phyllites. The top soil contains flaky particles in an unconsolidated state. These get easily disturbed in the presence of surface runoff. The slopes that are inclined at 30° to 40° does not suffer surface soil depletion during dry season. But during rainy season the picture is different; top soil flows like a viscous fluid. Surface runoff acts as catalyst to trigger off the slides.

For the past forty-five years landslides along the mountainous roads in Sikkim have been of serious concern to the vehicular traffic as well as to the government. Majority of the slides occur in areas where phyllites and schists are exposed. Normally, landslides occur after heavy thunder shower associated with cloud burst. In areas where land has been laid bare owing to deforestation and shifting cultivation, surface erosion and mud flow is severe.

Padamchen slide, Sikkim

Padamchen slide has developed on the left bank of Keu Khola, along the southwestern slope of Padamchen Range located at 101 km southeast of Gangtok. The slide has occurred 16 km northeast of Rangli on Rangli-Kupup road section.

Geomorphologically the area is dotted with lofty rides of about 3,000m and intervening valleys with uneven side slopes. The master drainage of the area is Rangli Chu and its tributary system. Keu Khola is one of the major tributaries. Tributaries feeding Rangli Chu from the north shows parallel drainage pattern along the southern slope of the Padmachen ridge. These are guided mostly by structural pattern of the country rock. Rangli Chu and Keu Khola are both deeply incised and flanked on either side by steep valley side walls. In this area summer monsoon is characterized by heavy intermittent showers during May to September. The average annual rainfall is 400 cm. About 75 per cent of annual rainfall is drained out as surface off and river discharge. The snowline exists at 4,000 m altitude; but sometimes it comes down at lower altitude.

The area has experienced major earth quakes in each and every decade. In addition, the

terrain is prone to minor tremors that occur more frequently. The rock types exposed in this sector belong to Darjeeling Gneisses group comprising of weathered to fresh garnet mixed biotite gneiss. Also, there are schists and quartz veins. The rocks are highly affected by numerous crisscross developed joint planes. The subsurface run-off is conducted by these joint planes as the parent base rock has little primary porosity.
Padamchen slide is classified as debris slide and debris flow. It has developed from the left bank of Keu Khola. The lateral spreading of the slide is recorded towards Beusa terrace in the north and Padamchen village in the south. Beusa Khola with a n umber of slope breaks is the principal transporter of debris material of glacial, peri-glacial origin. Some boulders are of 2-3 m in diameter. Padamchen slide appears to have been caused due to interaction of a couple of parameters that have contributed in the increase in shear stress. These are: toe erosion by Keu Khola and Beusa Khola, heavy precipitation and surface run off-creating pressure and excessive saturation, anthropogenic disturbances, road construction activity and deforestation.

Slope fall in Darjeeling Himalaya
The slide at Km40 from Sevak Bridge along NH 10, has been a major problem to road maintenance. The slope forming materials consist of heavily saturated clay-rich overburden. The road is along the left bank of the Teesta river that flows at about 30-40m below the road. The river takes a bend at this point and the road is at the convex side of river bank. The uphill slope is steep being around 70°-75°degree. The slide has advanced 170 m above the road and is still advancing. The slope forming material consists of angular rock pieces - mostly quartzite, phyllite and schists; embedded in predominantly clayey to silty matrix and is underlain by high level river terrace composed of gravel and sand deposits. These apart, two isolated exposures of quartz-mixed schists have been noted.
Though the slide movement is aggravated during monsoon and post monsoon period, lesser rate of movement is noticed during dry spell also. It creates successive slump cracks in the moving slide mass. It was observed that a perennial nala coming from beyond the crown of the slide has been cut off by the existing slide. The nala flow has found its way out through the slump cracks and slide scars. Thus, numerous springs eject out from swampy pockets within the slide mass and its roadside face. These springs and undercurrent continuously lubricate the slide mass.
During rains the slide mass is further saturated by surface runoff which flows over the successive slide scars and open steep arcuate cracks having concavity towards the direction of movement. The slide has thus become perpetual area of instability. The main and intermediate threat to the road seems to come from the slide mass overlooking the road; and this mass requires control.
The main aim of corrective measure should involve providing of extensive drainage of the slide mass, particularly in the vicinity of the toe region adjacent to the road, prevention of water percolation in the slide mass and restraining the movement of mass debris.

Landslide in Arunachal Pradesh
In the foothills the road connecting Kimin (Papum Pare district) with Ziro (headquarters of the Lower Subansiri district and previously the headquarters of Subansiri district of North East Frontier Agency) was initially constructed by army engineers during late 1950s for jeep and light utility traffic. Subsequently it was being utilized by heavy vehicles since 1960s. The road starts from Kimin at 150 m above mean sea level and meanders along the river Ranga up to km 45; thereafter it gains height up to Phu Joram and finally drops to Ziro valley. All along it passes through dense forest.
This road passes through geologically unstable areas consisting of friable sandstones and shales which are easily weathered and disintegrated. The slopes are steep. The rock strata are jointed with dip towards the road. Over stretches where there is plastic soil, slope failure has been noticed. The road follows the Ranga river over a distance of 50 km; when the river discharge is high flash flood occurs. Enormous quantity of debris containing huge boulders, logs/tree trunks roll down the river. Also, numerous tributary streamlets/ nallahs transport debris and uprooted trees and deposit those by the roadside.

Recent problems

Landslide is a major problem for the road connecting Dibrugarh with Upper Subansiri. Uprooted trees and boulders with other loose materials block the roads frequently during monsoon months. Landfalls are often due to construction work and human interference. A landslide swept through a labour camp at a construction site in Tawang on 22nd April 2016. At least 14 people were killed. Following a non-stop rainfall for three days on 13th July 2017 in the afternoon, a massive debris slide buried alive a couple of victims at Laptap village of Papum Pare district.

In July 2020, incessant rains triggered flood and landslides in Arunachal Pradesh. These natural calamities caused significant damages to roads, houses and low-lying areas and caused loss of life. Sixteen persons were killed when a massive landslide buried a thin tin-shed house.

On 10th July 2020 eight persons were killed in two separate incidents; in Tigdo village of Papum Pare district four members of a family were buried alive; other incident occurred at Modirijo, located in between Itanagar and Naharlagun where four people died alive after being buried under a landslide.

Landslide in Nagaland and Manipur

On 14th July 2017 a landslide wiped away a large part of NH 29 in Nagaland. On 3rdh July 2023 amid heavy rainfall, a massive boulder crushed a few cars stranded over Kohima-Dimapur National Highway. The incident took place at Chunou-Kedima, near a police check post. At least two persons were killed and three others were injured.

On 9th July 2020 a big part of NH 2, the lifeline of Manipur, was wiped away due to landslide. On 30th June 2022 a landslide occurred in the district of Noney, at 107 territorial army camp, near Tupul railway construction site under Jiribam-Imphal railway construction project. Eight territorial army personnel were killed. The mishap occurred near Ijel river valley where there is a dam on its course. Total death toll was 42, while another 20 people remained missing.

The landslide was attributed to weak base rock, fragile top soil, heavy rainfall and anthropogenic interference. Experts at Manipur University opined that it was due to poor lithological set up, fragile rocks, steep slope and unstable base rock. It was likely that water logged soil liquified and destabilized, causing the landslide.

Problems in the hills of Mizoram

Mizoram is geologically young comprising of sedimentary and partially metamorphosed rocks. The network of roads through rugged topography developed over highly fragile soft sedimentary rocks saturated with moisture, have been posing stability problems. Certain stretches of these roads are prone to repeated landslides. The landslides occur after the arrival of southwest monsoon in June when subsurface aquifers attain saturation level.

Rail-bridge collapse

Geologically Mizoram is relatively young comprising of sedimentary and partially metamorphosed rocks. The area is composed by rocks of Tertiary formation ranging in age from late Oligocene, Miocene to Recent. The Oligocene age of Barail group of sedimentary rocks is exposed near Indo-Myanmar border.

Much of the area is underlain by repetition of arenaceous and argillaceous sedimentary beds. These have deformed into a series of anticlinal and synclinal folds trending NNE-SSW with plunging direction in either towards north or south.

On 23rd August 2023 an under-construction railway bridge collapsed in Mizoram. The accident occurred around 09.30 IST at Sairang, a town about 20 km from Aizawl, the state headquarters of Mizoram. At least 26 workers were killed in the accident. According to the Northeast Frontier Railway, it happened during construction work in progress on the Bhairbi-Sairang New Line Railway Project.

The network of roads and railways under construction to connect the remote hill towns or locations of other importance, in yet unexplored northeastern Himalayas, are frequently facing problems of repeated landslides. Rock formations and major structural discordances strike along the mountain chains; roads approaching from the foothills towards the interior, traverse a rugged topography underlain by diverse structural zones composed of a widely variant rock type. These are soft sedimentary cum metamorphic rocks deposited in shallow water environment, subjected to highly intense orogenic deformation during Tertiary and Quaternary era, resulting in a complex fold system.

Due to heavy seasonal rainfall preceded by hot summer with high sunshine, surface rocks are often in a highly weathered and fragile state. Monsoon rain starts about 15/20 days earlier in the northeastern hills. If deforestation is done, slope fall is obvious. Endogenic movements are frequent in this highly active tectonic zone. The rugged and intensely folded young mountain chains experience frequent tremors. As a result, roads and other construction work are bound to be affected by landslides.

In the terrain of North Eastern Hills while planning a road alignment, it is to be noted that the limbs of the fold have hill-ward dip and not towards the valley. Though, most beds are openly folded, but at some places these are acutely folded, often asymmetrical, even overturned and disharmonic. Disharmonic fold poses serious problem for road construction. These folds are not uniform in pattern, some parts of the major fold being separately thrown up to form a number of miniature folds – all these are in a very fragile state in the perspective of civil construction work. Carbonaceous shale band which is very commonly associated with these sedimentary formations, act as a good lubricating horizon and adverse dip of it due to aforesaid structural disposition, causes sliding. A slight tectonic disturbance in the terrain could lead to a major landslide.

Case history

The territory is seismically active. For the past 150 years the region experienced 15 major earthquakes with magnitudes of 7 or more. Two very significant earthquakes occurred on 12th June 1897 and 15th August 1950.

Two of the active slides in the Mizo hills may be cited as case history related to earthquakes; Minpui Slide on Lungleh-Tuipang road and Zig Slide on Aizwal-Lungleh road. Available record indicates that Minpui slide initiated in 1950 during a period of heavy rain of about 140 mm in five days. This was preceded by a severe earth tremor. This slide becomes active during monsoon moths.

The crown of the slide is located at a height of about 100m above the road surface. The affected area extends vertically for about 107 metres and transversely for a width of about 150 m. The head scarp is fairly steep and free of vegetation cover. Towards the toe there is vertical drop of nearly 50 m. Towards the toe of the slide there small springs and wet grounds during the monsoon, which indicates that impervious sub-surface layer of slip surface that retained percolated ground water, hits the ground surface near the toe of the slide and percolated water is ejected out as springs. It has been observed that the slide has no apparent connection with any river flow; it appears to be a rock cum debris slide culminating in a mud flow during southwest monsoon. The lubricating surface is a thin shale band interbedded with sandstone, which has been dragged into an overturned disharmonic fold. Thickening of the shale band near the hinge of the folds results in widening the outcrop of lubricating surface.

The slide prone two zigs involving three legs of Aizwal-Lungleh road cause disruption of vehicular traffic during monsoon. There is intermittent viscous mudflow, and subsidence proneness of the road. Sliding mass contains huge unrotated blocks of sandstone mixed in a matrix of finer grained sandy materials. There is a conspicuous 5m wide zone of highly dragged shale overlain by massive sandstone. The bedding plane in between the two stratum is affected by faulting. The drag fold gradually dies out towards depth where the rock grades into soft and friable shale. The cause of slope movement, in this case, appears to be squeezing out phenomenon of the softer layer due to the weight of an overlying more rigid layer.

LANDSLIDES IN WESTERN GHATS

In the hilly terrain covered by the Deccan Traps, landslides and development of cracks in the ground are common over rain-ward side of slopes. The phenomenon is also related to the mutual relation of the topography and underlying lithological components. Thick basalts form the escarpments and the vesicular varieties form the slopes. Most of the slips occur due to the loss of the shear strength at the interface with the underlying rock which is generally amygdaloidal / vesicular lava flow with a slope up to 50 degree.

The traps form an ideal topography for accumulation of the overburden as well as its sliding. All the landslips follow heavy rains which percolates deeper into the subsurface and lubricates the interface of the overburden and parent base rock.

When the shear strength is reduced to the optimum, the tangential force provided by the overburden itself comes into play resulting in the movement. After the initial movement along the underlying rock, the slip surface shears through the overburden itself. In most of the cases the hydraulic pressure might be playing an important role as indicated by the sprouting springs in the root area after the slide has taken place.

Seismicity is also one of the main causes of landslides. Following the Koyna earthquake in December 1967 adjacent to Koyna reservoir premises, tremors of minor to medium magnitude (2-5) are quite frequent in this part of the Western Ghats especially in Ratnagiri district. As such, it can be presumed that unstable tectonic set up is playing significant role in triggering rock fall.

Landslides in Pune, Maharashtra

On 19th July 2023 at approximately 22.30 hours, a landslide occurred in Raigad, Maharashtra. It was due to torrential rain and resulted in at least 26 deaths, with more than 100 entrapped under debris; most of the victims were rescued.

Irshalwadi was a picturesque village at around 1128 m above mean sea level, deep inside the Sahyadri forest range (Western Ghats) near Irshalwadi Fort in Raigad district of Maharashtra. Its 228 inhabitants, residing in 48 households, used to walk about one hour from the foothill zone to reach the village up on the hill. On the night of July 2023, Irshalwadi was wiped out after a massive landslide.

On July 24, 2021, Taliye village was wiped out, 85 lives were lost. Earlier, on July 30, 2014, 151 residents of Malin, a tribal village in Ambedgaon taluka, Pune district, Maharashtra died in a landslide. Soon after the Malin tragedy, government authorities, geologists and environmentalists cited two possible causes behind the mishap – deforestation for terrace cultivation of paddy in the upslope region of the village and large-scale flattening of the foothill slopes in the downstream of the village. Terraces ang flat grounds encourage stay of surface run off over the land and percolation of water subsurface. Thus, surface soil loosens up after continuous rainfall.

Remedial measures: In the alternate slope and scarp topography of the Deccan Traps, any overburden of boulders, semi-volatile clay overlying an amygdaloidal/vesicular basalt flow, is liable to slide if the rainfall is heavy. In most of the cases there is no prior indication of the impeding movement. Under this circumstance it is difficult to adopt effective protective measures. However, where human habitation is endangered due to development of cracks in the vicinity, rehabilitation in safer locality could be arranged. Over flat-semi flat tablelands, cracks could be filled up with fine grained soil.

Landslides in Kerala

Due to climate change and global warming, Kerala experienced five low pressure system development and depression during the southwest monsoon season in August 2020. This combined with strong winds over the Arabian Sea resulted in cloudbursts that saturated the top soil. Moisture reached bedrock. Overflowing rivers and sheet flood came down fast along moderate to steep slope. That year, Kerala experienced 190 percent increase in rainfall during the first ten days of August (compared to the average downpour of previous 50 years). Huge sheet flow caused landslides, destruction of forests and plantations, ruining settlements and roads / highways. Coastal towns experienced tidal bores that further impeded the quick downstream flow of surface run off. Five districts of Kerala were flooded on 7th August 2020. These are Idukki, Wayanad, Malappuram, Thrissur and

Kottayam. Major reported incidents in relation to flooding include a landslide in Idukki district on 6th August 2020. It claimed 66 lives and an Air India plane crash that caused the death of 421 people. Factors contributing in landslides are deforestation and slope alteration for agriculture, plantation, mining and quarrying, widening of existing roads. Rain conservation pits, insufficient drainage system to combat surface runoff, construction work (buildings and roads) along stream, river and flood lines are also responsible.
An analysis of the most significant landslide in the Pettimudi tea estate, Munnar, Idukki on 10th August 2020, found that the area experienced extremely heavy rainfall as classified by India Meteorological Department 'heavy' during 3rd to 10th of August 2020. Landslide occurred at 22.45 hours. It was categorized as 'rain induced debris flow'. This landslide was characterized by rapid water flow over a steep slope flowing at a high velocity from the rocky outcrops through the forests, collecting loose materials along its course to the tea plantation and workers' living quarters below. Additional landslides occurred in Mundakkai, Kakkayam in Kozikode, Nilambur in Malappuram and in Kottayam.
Earlier, on 16th August 2018 severe flood affected Kerala, after unusually high rainfall during the monsoon season. It was the worst flood in Kerala recorded in this millennium; over 483 people died and 15 went missing.

Common causes of flood and landslide: Over 90 per cent reservoir storage was full even before the onset of the rainy season and the unprecedented heavy rainfall in the catchment areas of major reservoirs led to the disaster. Hill slopes of Malabar coast experienced slope fall and uprooting of trees. While this was an extreme weather event, man made situations like cutting trees for road and construction work disturbs the ecological balance.

Measures for prevention
Anthropogenic disturbances like bursting of bed rocks by dynamite explosion, movement of heavy vehicles along highways across the hills, deforestation Anthropogenic disturbances like bursting of bed rocks by dynamite explosion, movement of heavy vehicles along highways across the hills, deforestation and urban expansion are to be controlled.

Protective and Preventive measures
- Reforestation.
- Avoiding construction work over rock stratum susceptible to landslides. Avoiding many zig zags on the same side of slope, especially dip slope.
- Avoiding portions of middle slopes that are continuously affected by debris and boulders falling from upper slopes.
- Construction of road foundation over bed rock (where surficial un-consolidated material is not very thick).
- Protection of toe slope, diversion of flow of water towards the centre of the river channel. A peripheral catch-water drain above the crown of the slide.
- Treating up-hill and down-hill slopes by spraying two coats of cut back bitumen to prevent percolation of surface run off and to provide cohesion at the surface.
- Breast wall in combination with a deep roadside drain to trap the surface runoff over the hill slope and also for trapping the seasonal springs.
- Road retaining structures (dry stone masonry filled crates in wire mesh).
- Geotextile engineering work to control slope failure.
- Construction of a bye-pass tunnel.
- Construction of a subway where base rock is strong enough for digging.
- Consideration of litho-structural aspects: avoiding steep dip slopes and fragile rock surface.

It may be mentioned that remedial action plan would vary from site to site as each and every landslide is unique in terms of lithological components, water/moisture content, surface runoff, slope/gradient, anthropogenic disturbances, etc. Joint Landslide Prevention Committee is to be formed involving Forest Department, Soil Conservation Department, Horticulture and Agriculture Departments, Irrigation and Hydel Power Commissions, Geological Survey of India, Survey of India, Border Road Research Department, National Highway Authority, Public Works Department, Central Water and Power Commission, India Meteorological Department.

Temporary and permanent measures to solve the landslide problems should be identified. Temporary measures are necessary for opening up of traffic for communications after any disaster. For permanent measures detailed investigations should be undertaken to evolve permanent solution. Permanent measures are more expensive, like diversion of roadway.

CONCLUSION

The country enjoys heavy seasonal rainfall that produce bountiful surface runoff. Landslide hazards get boosted during southwest monsoon. Where rocks are unconsolidated and fragile, any construction work is to be planned wisely taking sufficient precaution. Our nation needs disaster free development work. However, landslides could get initiated due to snowfall also. Frost heaving and wedging are the weathering agents under peri-glacial environment. There had been instances of heavy landslides where the rainfall is only 3 cm. The type of failure of a slope and occurrence of landslides and toe erosion needs to be diagnosed properly.

Major insights

- All the administrative units bordering the northern Himalayan mountain chain, the northeastern hills, the Western Ghats are prone to landslides.
- Landslides are often due to prolonged heavy rainfall, cloudburst, glacial lake burst.
- Loose surface soil, fractured and jointed rocks when exposed to weathering contribute in scree formation.
- Massive slope fall may lead to uprooting of trees.
- Water/ frost is the principal agent of mass-wasting.
- Where slope failure is uncontrolled, evacuation is advised.
- Construction work and urban expansion is adding problems.
- Unwise hill-side cutting of slopes for rail-road construction, tunneling, terrace cultivation may be detrimental for ecological stability.
- Same geo-engineering design would not be corrective and effective measure for each and every landslide.

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